

# MULTIPLE BEPPoSAX OBSERVATIONS OF IC 4329A TO PROBE THE ORIGIN OF THE COMPTON REFLECTION COMPONENT IN SEYFERT 1 GALAXIES

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## ABSTRACT

IC 4329A is the brightest known Seyfert galaxy in hard ( $\sim 2\text{--}30$  keV) X-rays and is likely to be representative of Seyfert 1 galaxies as a class. A recent 100 ks *BeppoSAX* observation (Perola et al. 1999) clearly confirmed the presence of a warm absorber, a reflection component ( $R \sim 0.6$ ), and a high-energy cut-off in the power law at  $E_c \sim 270$  keV. Its richness in spectral features, combined with its large flux ( $\sim 1.6 \times 10^{-10}$  erg cm $^{-2}$  s $^{-1}$  between 2-10 keV), make this target ideal for multiple observations (in particular with *BeppoSAX*) to search for spectral variations. Results obtained from 3 follow-up observations (40 ks each) are presented here. The first and most important goal of this study was to probe the origin of the Compton reflection component observed in Seyfert galaxies by monitoring the variability of the reflection continuum and Fe K $\alpha$  line in response to primary continuum variations. The second goal was to search for variability in the high energy cutoff. We obtain however no conclusive results on any of these issues. In fact, all four observations unfortunately caught the source at almost the same flux, showing only little, and marginal, spectral changes between different observations.

KEYWORDS: galaxies: individual (IC 4329A) - galaxies: Seyfert - X-rays: galaxies

## 1. INTRODUCTION

*Ginga*, *ASCA* and recent *BeppoSAX* X-ray observations of Seyfert 1 galaxies strongly support a general *observational* framework that includes: ionized absorption by a warm absorber (WA), a steep intrinsic power-law continuum, a Compton reflection hump and associated neutral FeK $\alpha$  line (narrow and/or broad), and a high-energy cutoff ( $E_{\text{cutoff}}$ ). These observational results have raised the following questions:

- What is the location of the X-ray reprocessor? Is it the accretion disk, the broad-line region (BLR) and/or the molecular torus? Is the answer the same

for all Seyfert 1s?

- Where is the location of the WA? Is it within the BLR and/or the molecular torus or is it external to them? Is there only one WA?
- Does  $E_{\text{cutoff}}$  differ from source-to-source (as currently shown by *BeppoSAX*, Piro 1999, Matt 2000) or is it variable with time and/or flux in any single object?

In order to address these questions, we have performed multiple (4) observations of the prototypical Seyfert 1 galaxy IC4329A to obtain time-resolved spectral constraints on the WA, reflection continuum, Fe  $K_{\alpha}$  line and, possibly,  $E_{\text{cutoff}}$ . This is potentially the best way (see also Weaver 2000) to establish whether these observational features are produced from material near the source (e.g. the accretion disk, in which case short lags,  $<1000$  s, are expected between the reflection and continuum variations) or farther away (e.g. in the BLR or torus, in which case longer lags of at least  $\sim 10^{6-7}$  s are expected).

## 2. THE MULTIPLE *BEPPOSAX* OBSERVATIONS

IC 4329A ( $z = 0.014$ ) is a Seyfert 1 galaxy well studied in X-rays (Miyoshi et al. 1988; Piro, Yamauchi & Matsuoka 1990; Fiore et al. 1992; Cappi et al. 1996) and hard X-rays (Fabian et al. 1993; Madejski et al. 1995; Zdziarski et al. 1995a). It offers the best opportunity to address the above mentioned variability issues because it is among the brightest known Seyferts in X-rays ( $F(2-10\text{keV}) \sim 1.6 \times 10^{-10} \text{erg cm}^{-2} \text{s}^{-1}$ ) and shows only *moderate* variability on short ( $< \text{day}$ ) timescales, but large variability on longer timescales (a factor 2-3 in a few days), both below and above 10 keV (Done, Madejski & Zycki 2000; Fabian et al. 1993).

*BeppoSAX* observed IC 4329A in 1996 for 100 ks (Perola et al. 1999), and then subsequently 3 times in 1998, with the 3 observations spaced approximately 5 days apart. As expected, the source did *not* vary much *within* each observation. Unfortunately, it did not vary much *between* the 4 observations either (see Fig. 1), despite the large and systematic flux variations typically observed in IC4329A by RXTE (Done, Madejski & Zycki 2000).

Spectral ratios were produced between all observations, in search of any model-independent spectral variations (Fig. 2). We find marginal evidence for variability of the spectral features at  $E < 2$  keV and at  $E = 8-10$  keV, but we find no clear variations in the Fe $K_{\alpha}$  and reflection component intensities, as well as in the high- $E_{\text{cutoff}}$ . The variations at low energies are most likely due to variability of the ionization state of the WA responding to continuum variations, but complications due to the presence of a possible scattered component and/or intrinsic soft (excess) component cannot be ruled out.

Spectral fitting of each observation with a complex model including 2 absorption edges, a steep power-law continuum, a reflection component with associated Fe $K_{\alpha}$ , and a high- $E_{\text{cutoff}}$  gave best-fit parameters similar to those reported by Perola et

al. (1999) with somewhat larger errors (e.g.  $\Gamma \sim 1.85 \pm 0.1$ ,  $R \sim 0.6 \pm 0.2$ ,  $E_{\text{cutoff}} \sim 250 \pm 100$  keV). Fig. 3 shows the marginal variations of the FeK line intensity and equivalent width. Fig. 4 shows the (similar) best-fit broad-band spectra of two different observations.

The most interesting result of the present analysis is that despite a 30% flux increase between obs. 1 and obs. 2, the line intensity became surprisingly weak (compare Fig. 1 and Fig. 3). During the higher flux obs. 3 the line re-established its typical value of  $\sim 100$ -150 eV, though. In other words, there is some evidence (at a  $\sim 2\sigma$  significance level) that the Fe K $\alpha$  line *does not* follow “instantaneously” (at least within 40 ks) the continuum variations, but it *does* on a timescale between 4–10 days.

### 3. CONCLUSIONS

- Moderate variations of the absorption structure, most likely related to the warm absorber, are apparently detected but require further investigation for more quantitative conclusions.
- Despite the unprecedented statistics of these observations, we find *no* significant spectral variations of the Compton reflection continuum, the power law spectral index and the high-energy cutoff. This is probably because *BeppoSAX* unfortunately caught IC 4329A at a not too different flux level (30% variation) in all four observations hampering, thereby, any spectral variability.
- There is marginal evidence that the FeK $\alpha$  line is being produced by the outer regions of the accretion disk in IC 4329A, thereby suggesting a possible explanation for the lack of a clear broad FeK $\alpha$  line in this object.

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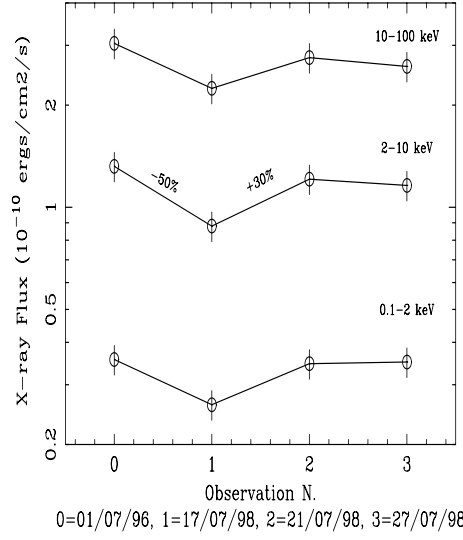


FIGURE 1. 0.1-2 keV, 2-10 keV and 10-100 keV flux of IC 4329A during Obs. 0 (top pannel),  $\frac{Obs.2}{LongObs}$  (the long 100 ks Obs.), Obs1, 2 and 3.

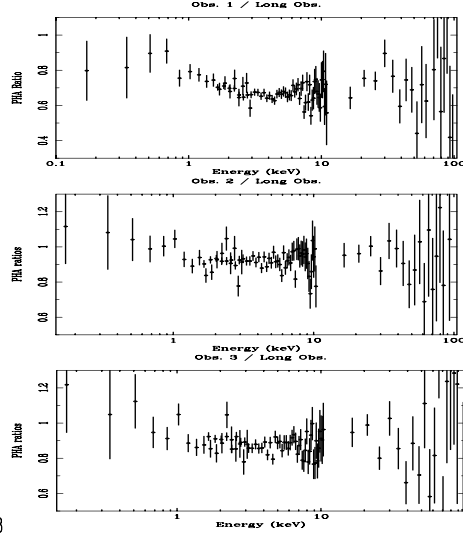


FIGURE 2. Spectral ratios of  $\frac{Obs.1}{LongObs}$  (top pannel),  $\frac{Obs.2}{LongObs}$  (mid pannel) and  $\frac{Obs.3}{LongObs}$  (lower pannel)

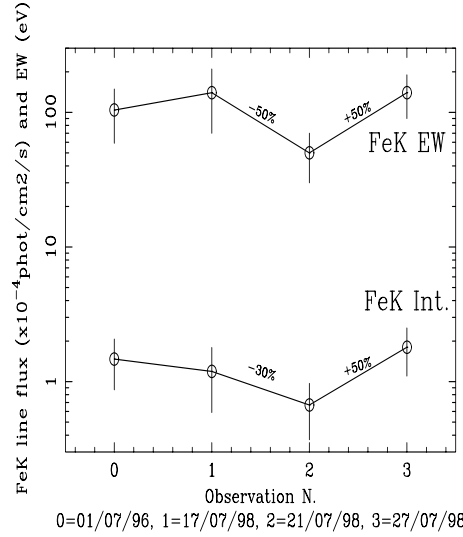


FIGURE 3. FeK line EW (upper points) and Intensity (lower points) during Obs. 0,1,2 and 3

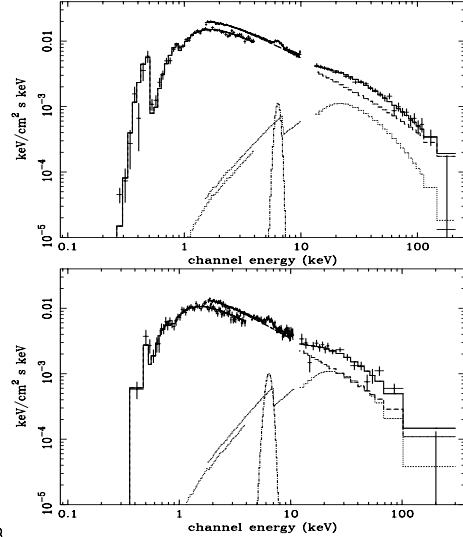


FIGURE 4. Best-fit unfolded spectra during the long 100 Ks Obs. (top) and during Obs.1 (bottom) which illustrate the similarity of the spectra.